(This is the unabridged text of a talk by Professor D.D. Kosambi to the Rotary Club of Poona, on July 25, 1960.)

Atomic Energy for India

The word energy is associated in the minds of most of you with steam engines, electric supply, diesel or petrol motors, water-turbines and perhaps windmills. The word evokes others like horsepower, kilowatts, and calories; perhaps also electricity and petrol bills, price per ton of coal, and increased taxes for the Five-year Plans. I want only to point out to you that these technical, social and economic considerations go very deep, down to the foundations of human society. With the coming of atomic energy, they have reached a stage, which is critical for the whole of mankind, far above mere personal considerations.

We rarely think of the simplest and most familiar type of energy, namely that derived from food – though far too many in this world still have to think of food as the one overwhelming need for their lives. Man needs from 2000 to 4000 calories of nutritional energy per day, according to the climate, conditions of work, and type if food taken. In our ordinary discussions of a balanced diet vitamin etc. this elementary fact is often forgotten; namely that the value of food depends upon the amount of energy it can release in the human or animal body. To make this energy available in the digestive system, man needs to have his food cooked by fire, which means another form of energy obtained by burning fuel. The history of mankind begins with the first steps above the animal stage, when man learned to control fire, and began to produce food instead of just gathering it.

The next step, the formation of human society proper, with division of labour and differentiation of social functions, was made possible only by more power: that of animals such as cattle or horses for agriculture and transport. Human labour-power was also used in greater quantity, whether slave labour or that of paid drudges. Other sources such as windmills and water wheels helped. The industrial revolution could not have been realised before the discovery and the extensive use of the steam engine, in the early 19th century. Man succeeded in the conversion of fire-energy into mechanical work. Electricity came later in that century. It could be generated with or without the steam engine, as for example waterpower or the windmill; its chief advantage lay in the transmission of energy to places distant from the point of generation. The steam engine used directly meant chains, driving rods, gears, cables, or some such mechanical transmission. You know how much human society has been changed by electricity in a single lifetime, say the life-time of Edison.

What is the ultimate source of all such power? Food- grains, fruit, nuts etc. store their energy from sunlight, which is absorbed by the living plant, along with carbon dioxide from the atmosphere, water vapour and other substances. Cellulose thus made is also the main source of the energy stored in firewood. Coal and oil are simply organic matter converted by deep burial in the earth for millions of years. Hence, all these forms of energy come from the sun, the difference being in the method by which the energy is stored. The chemical processes involved may be described as molecular change. The breakdown of the energy in food and fuel is also chemical and molecular. The molecules may change, their atoms do not. For wind-power, the sun heats up some of the air, which rises, and is replaced by other, cooler

air. These air-currents drive the windmill. Water- power is similarly drawn from the sun without chemical change. The water evaporated by the sun's heat rises, forms clouds, and comes down again as rain. What we utilise is the how of rainwater from a higher to a lower level.

The electric energy, which appears on out monthly bills (in the few Indian homes fortunate enough to have the supply) is measured in kilowatt-hours. One-kilowatt hour is equivalent to one horsepower for about an hour and twenty minutes. It is also equivalent to a little more than 860,000 calories of heat. But these are the equivalents when nothing is lost in the change from one form to the other. In practice, something is always lost. No transformation of energy is a hundred percent efficient, and most of them are decidedly inefficient. The machine loses a good deal of energy in friction; electricity is lost in transmission, and by leakage; heat is radiated away. These losses are physically inevitable, and a fundamental property of matter. But energy is also a fundamental property of matter, apart from the chemical changes and mechanical processes. Matter cannot be destroyed by ordinary mechanical or chemical processes. But if it could be annihilated in some way, an equivalent amount of energy must appear. This was finally proved by Einstein, who summed it up in the formula $E = mc^2$ which gives the absolute energy available from a given amount of matter.

Atomic energy is fundamentally different from molecular energy. For the first time in history, man has been able to duplicate the solar processes for himself on earth. Solar energy depends upon the breakdown of the atomic nucleus, with the resultant emission of heat, x-ray radiation, longer electric waves, and particles such as electrons, neutrons and the like. These last correspond to the smoke and ashes of ordinary fuel, but are much more dangerous to man. The electricity cannot be utilised directly. The main useful output of atomic nuclear reactions is still the heat, which has then to be converted into power like any other source of best. This might seem wasteful, but is much less wasteful than other forms of conversion. The animals, including man, cannot convert more than a limited amount of food per individual into energy, and that too not without considerable waste. Not only is the animal power plant quite inefficient, but it has to be stoked and fed all the time, whether any energy is utilised or not. You all know the low efficiency of coal and oil fuel. Hydro-electricity is better, but limited by lack of flexibility, and restriction to certain favourable localities.

What can humanity do with atomic energy? We must distinguish between what is now technically possible and what might theoretically be achieved in the very distant future. The most that has actually been done is to break down uranium nuclei, and to use the energy liberated. Other atomic nuclei can be broken down, but generally the process eats up more energy than it liberates. You know that this process has been misused. The atomic age arrived with a bang at Hiroshima and Nagasaki, in the form of a most deadly bomb. Its main use since then has been as a military and political weapon in the cold war, with which certain powers have tried to cow their opponents. The sun gets most of its energy from fusion. Four nuclei of hydrogen are squeezed together under immense heat and pressure to form one of Helium. A certain amount of mass left over in the process is converted directly into energy, by Einstein's Law. This has been done on earth in the hydrogen bomb. No materials known on earth can withstand the temperatures of fusion energy. If the available uranium were properly shared, we could convert many deserts into veritable gardens, industrialise the densest Amazon jungles, and free mankind from the worst forms of drudgery. This is no

longer a technical problem, but a social one. A few pounds (about 8) of uranium sufficed to run a great submarine for seventy days. Automatic power plants could in theory be built which could be refuelled by air once every few months. Half a dozen trained men could run them. These plants could be located in any part of the world, without railways, waterways, or even road communication. But is the world prepared for this? The main question that most of you will ask is: What is the investment value of atomic energy? If the preliminary research and refining is to be done, there is virtually no investment value, for the private sector. The whole affair is fantastically costly. Those who say that atomic energy can compete with thermal or hydro-power, carefully omit to mention the fact that the preliminary costs have always been written off to someone else's account usually that of some government. Only in some socialist countries, where uranium is relatively plentiful, and new lands have to be opened up, is it possible to utilise atomic energy properly. Even there, military considerations play a considerable part, because of the cold war.

It is true that the known resources of radioactive material in the world exceed those known for coal. But the cost of uranium is artificially high. Then there is also the question of by-products. Animal by-products are good fertilisers; the skins and meat can also be used. For human beings, the by-products are taken care of by a good sewage system and the dead bodies by funerals. In industrial countries, the average temperature over cities (e.g. London) goes up by a couple of degrees Fahrenheit, due to the use of coal. There is also the smoke, acid deposits that corrode buildings, carbon monoxide poisoning of the air by petrol fumes, and smog. These are trifling in comparison with the waste products of atomic power plants. The pile has to be very heavily shielded to screen harmful radiation. No one knows where to put the radioactive wastes from uranium piles. Every possible mine or pit is being rapidly filled up in the USA; the sea is unsafe, the rivers even more so. This is best brought out by the effects of atom-bomb tests. The fallout is found ah over the world. The Bikini tests made grass in California radioactive and poisoned fish that would otherwise have fed Japanese a few thousand miles away. Excessive doses of radioactivity always came serious changes in all living organisms. Some of these changes lie in the mechanism that enables the organism to breed. Most of these hereditary changes are lethal; that is, they kill the organisms born in the next generation. The Japanese have followed up persons exposed to atomic radiation at Hiroshima. Many of the children born to women who have been so exposed can hardly be called human; but they do not live to grow up. The real danger lies in the minute genetic change that does not show itself for some generations. It is known from experiments on smaller animals that these changes, when fully developed, may lead to incurable mental derangement within a few generations. By the time we know what the effect on mankind is going to be, it will be far too late to do anything about it. The changes will have been bred into millions of human beings of that generation and remain thereafter. This is not a disease, or an infection that I am talking about, but hereditary insanity, physical degeneracy, and worse. The only cure is to stop all atomic tests immediately, and to take great care that the waste pro- ducts of atomic power stations for peaceful purposes will be safely isolated. The advanced countries have quietly reduced their atomic power programs. The prestige of having atomic power stations does not compensate the extra expenditure or the extra danger involved,

Where does that leave us in India? We do need every available source of power quickly. Can we utilise atomic power for national progress? This question has already been answered

in the affirmative by the high command. The papers inform us that another hundred crores or more are to be devoted to this purpose beyond undisclosed millions already spent. It was announced in August 1956 that India had joined the ranks of the atomic-energy producing countries. Actually, we were not then producing any atomic power. Though a second reactor costing another ten crores of rupees has gone into operation, and the staff has reached over two thousand highly trained graduates, we still, produce no utilisable atomic power. The setting up of atomic power stations in other countries is now quite easy. Even China has one giving 7000 kilowatts since last year, and may build more. The USA, UK, USSR, France, Canada and some other countries could build one or more for us--if we are willing to pay the cost. The question is whether this cost is worthwhile.

I do not propose to answer this question, because all of you here are intelligent to work out the answer for yourselves. But I do wish to point out that the main work in producing atomic energy has already been done without coat to India by a permanent source, which has only to be utilised properly. This generous source is the sun, which goes on pouring its blasting rays into every tropical country, at an uncomfortable rate. Can solar energy be used directly?

The answer is yes. The USA, Russia or England, for example do not receive so much direct solar radiation as India. There is no reason why we should ape them in all things, including the development of atomic energy at a fantastic cost with low-grade Indian uranium. On an average day, every hundred square metres (1100 square feet) of area will receive about 600-kilowatt hours of heat. This comes to over 160 pounds of high-grade coal, or more than 16 gallons of petrol, in energy equivalent. If it could all be utilised at 100% efficiency, we could evaporate some 240 gallons of water per day. At present, the best known efficiency of utilisation is by solar batteries, which are between 11% and 15% efficient. The Americans are already using such batteries to boost telephone currents in long-distance lines. If I could use such batteries on my own bungalow roof, it means 7 kilowatts for every hour of average sunshine, say 60-kilowatt hours per day. This would give my family enough power for all cooking, lights, hot water gadgets, (vacuum cleaner, fridge) air-conditioning, and still leave enough for an electric automobile run on storage batteries. The Russians produce enough steam power from solar energy to supply all the needs of a modern town of over 15,000 inhabitants in the southern USSR. Even as early as 1876, a 2.5-horsepower steam pump was run on solar heat in Bombay. A striking instance of the immense reach of solar power comes from the space-satellites, which send their information to earth by radio transmitters that run on solar batteries. The best of them continued to communicate with our globe from well over 20 million miles away.

It seems to me that research on the utilisation of solar radiation, where the fuel costs nothing at all, would be of immense benefit to India, whether or not atomic energy is used. But by research is not meant the writing of a few papers, sending favoured delegates to international conferences and pocketing of considerable research grants by those who can persuade complaisant politicians to sanction crores of the taxpayers' money. Our research has to be translated into use. The catch in solar energy is its storage. The current you may want at night can be produced irregularly in the daytime. This is not an insoluble difficulty. Quite efficient forms of storage batteries are known. It is possible to combine several uses with mechanical storage. For example, water could be pumped up into 50-foot village towers during sunlight hours, and then allowed to run out for irrigation, or home use, through low-

pressure turbines that generate electricity whenever wanted. This is not very efficient at the second stage, but the main purpose of augmenting our poor water supply will have been efficiently served, village-by-village.

The most important advantage of solar energy would be decentralisation. To electrify India with a complete national grid would be difficult, considering our peculiar distribution of hydropower and thermal resources. With solar energy, you can supply power locally, with or without a grid. Solar power would be the best available source of energy for dispersed small industry and local use in India. If you really mean to have socialism in any form, without the stifling effects of bureaucracy and heavy initial investment, there is no other source so efficient. Take the simple problem of reforestation, which alone on change India's agriculture, preserve her rapidly eroding soil, and increase production. This problem is insoluble unless people have cheap fuel for cooking, so that they need not cut down trees. The solar cooker if it worked, would have been the answer. We know that the cooker produced some years ago with such fanfares and self-congratulations is useless. Even a schoolboy should have known that the pot at the focus of the solar cooker, being nickelled and polished, would reflect away most of the heat. But our foremost physicists and research workers, who rushed to claim personal credit and publicity, did not realise this. That is the result of paper research and research for advertisement. If we get over this fundamental hurdle, we have the real cost-free source of atomic power, the sun, at our disposal, for more than eight months of the year.

Solar energy is not something that any villager can convert for use with his own unaided efforts, at a negligible personal expenditure, *charkha* style. It means good science and first-rate technology whose results must be made available to the individual user. The solar water heater is the simplest to manufacture a black absorbing grid like an automobile radiator, and an insulated storage-tank. No moving parts are involved. The water can be delivered much hotter than needed for a bath, but below the boiling point. Such heaters are already used successfully in Israel and elsewhere, and would save a great deal of fuel by themselves in the Indian household. For the steam engine, it is necessary to concentrate the sun's rays, usually by a light silvered concave re- hector which moves with the sun. These are also quite practicable, and in use. Direct conversion of sunlight into electricity is familiar to many of us as the photoelectric cell, and the photometer used for correct exposure. These are very simple and efficient to use, but cost more money to make. The technique has now been simplified and the cost reduced by careful study of semi-conductors. The most effective solar battery of which I have any knowledge is based upon silicon-zinc crystals. Their production, too, is commercially successful, but needs still more research--which continues uninterrupted in other countries. The Chinese use semi-conductors directly to produce enough electricity even from the waste heat of an ordinary kerosene lamp to run a radio set; their appliances are on the international market now. What India could use best in this way still remains to be determined. The principle involved in the use of atomic energy produced by the sun as against that from atomic piles is parallel to that between small and large dams for irrigation. The large dam is very impressive to look at, but its construction and use mean heavy expenditure in one locality, and bureaucratic administration. The small bunding operation can be done with local labour, stops erosion of the soil, and can be fitted into any corner of the country where there is some rainfall. It solves two fundamental problems: how to keep the rain-water from flowing off rapidly into the sea, unused; and how to encourage local initiative while giving direct economic gain to the small producer. The great dams certainly

have their uses, but no planners should neglect proper emphasis upon effective construction of the dispersed small dams. What is involved is not merely agriculture and manufacture, but a direct road to socialism.

Every notable advance in man's control over new sources of energy has been hampered by outworn superstition or obsolete social forms. Fire is regarded today as a convenient tool it the service of humanity. Primitive man thought ii necessary to worship fire as a god. *Agni* received human and animal sacrifice; vestal virgins might be dedicated to his service. Is it less miserable a superstition that calls for the sacrifice of millions of men and animals, living or as yet unborn, to atomic tests and radio- active fallout? It seemed inevitable to Victorian England that dreadful industrial slums should accompany the first large scale use of the steam engine; it also seemed necessary to conquer many colonies for supply of raw materials and as market for the finished goods of the factories that the steam engine first made possible. We claim to know better now. If so, has the time not come to change society so that the new discoveries will serve the needs of all mankind rather than the perverted greed of the few? Then, and only then, will it be possible to determine how much effort should be spent relatively on the development of the various.

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